UCR | College of Engineering- Center for Environmental Research & Technology

Effect of Natural Gas Fuel Composition on Vehicle Emissions and Performance

2010 Clean Energy & Air Quality Virtual Conference Series

Air Quality Implications of Increasing Alternative Fuel Use

November 2, 2010

Presented By:

Tom Durbin, George Karavalakis, Kurt Bumiller, Mark Villela, and Wayne Miller

University of California, Riverside
Bourns College of Engineering
Center for Environmental Research and Technology

Project Motivation

- Liquefied natural gas (LNG) and NG demand will likely increase over the next decades.
- California's current needs met largely by domestic and Canadian imports
  - LNG imports from Asia or other parts of the Pacific Rim
  - "grand fathered" local sources of NG
- NG from a wider range of sources is expected to have more variation in composition and properties.
- Broader ranges of NG composition and properties could impact performance and/or emissions of vehicles.

Program Plan

- Project Advisory Committee oversees the planning and reporting for the project.
- A 2-phase program was developed.
- Phase 1: Light-Duty Vehicle Testing
  - 2 vehicles on 4 blends.
- Phase 2: Chassis dynamometer testing of heavy-duty vehicles.
  - 3 vehicles on 6-7 blends.
- Project funding from California Energy Commission (CEC), CARB, and SCAQMD

NG Light-Duty Vehicle Testing

- Testing in CE-CERT's Vehicle Emissions Research Laboratory
- 2 Vehicles
  - 2006 Honda Civic GX, SULEV certified, OEM
  - 2002 Ford Crown Victoria, ULEV certified, OEM, older technology
  - 4 fuel blends
- Test cycles are FTP and Unified Cycle with 3 replicates on each fuel
  - Power curves on each of the blends
- Status – Testing completed, draft memorandum under review

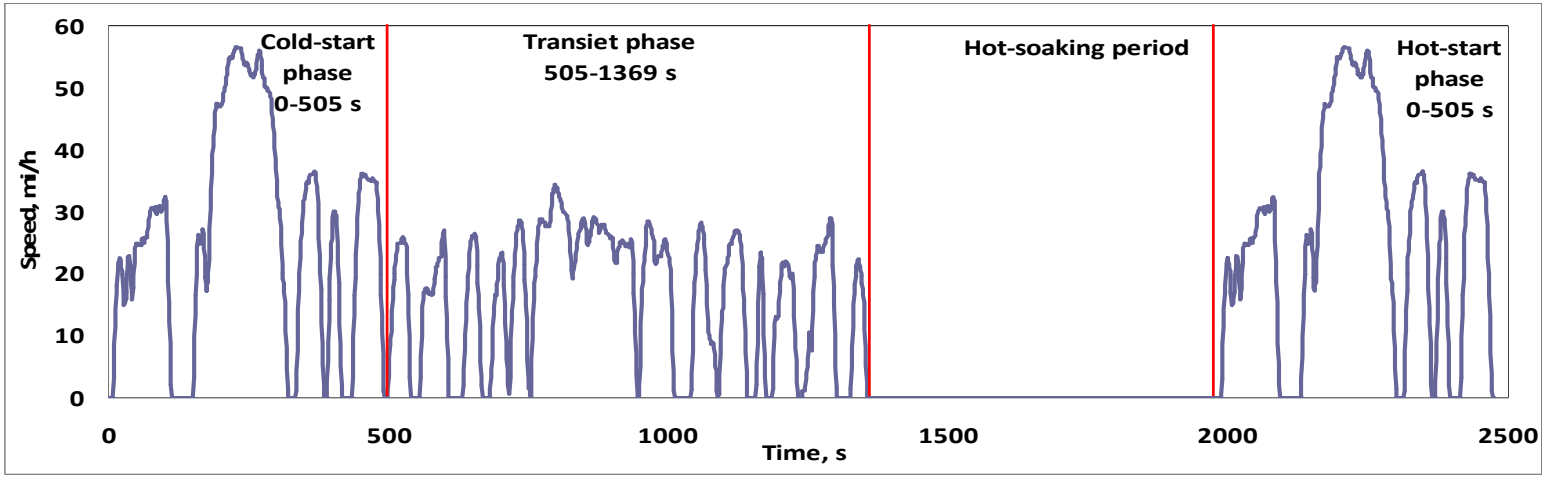
Gas blends for Testing

- Average So. Cal. Gas pipeline gas.
- CARB specification natural gas - with average properties.
- High Wobbe number gas – extreme local production gas
- The High Wobbe number gas blended down to 1385 w/ N_2.

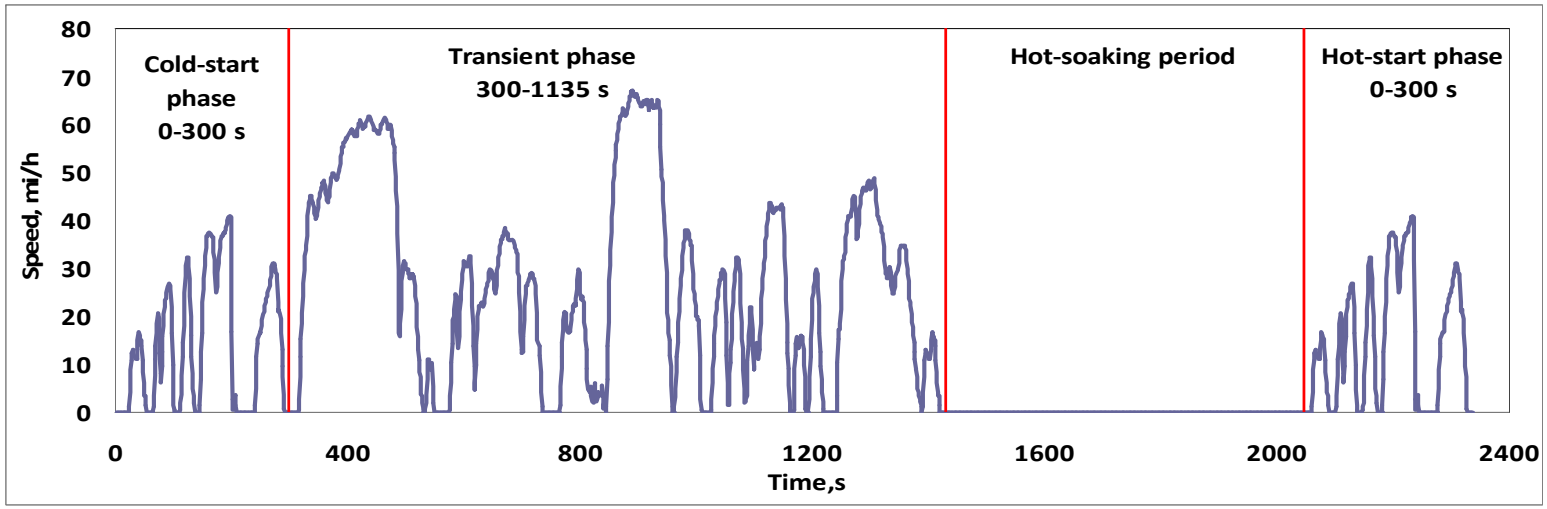
Gas #	Description	methane	ethane	propane	I-butane	N2	MN	Wobbe #	HHV
1	Baseline, Line gas	96.08	1.78	0.37	0.16	1.62	100	1344	1020
2	CARB spec gas	90.3	4	2		3.7	89	1330	1038
3	Hi Wobbe	84.03	9.36	3.76	1.85	1	69	1437	1175
4	modified gas 3	84.03	6.86	3.76	1.85	3.5	71	1385	1131

Light-Duty Test Cycles

- FTP

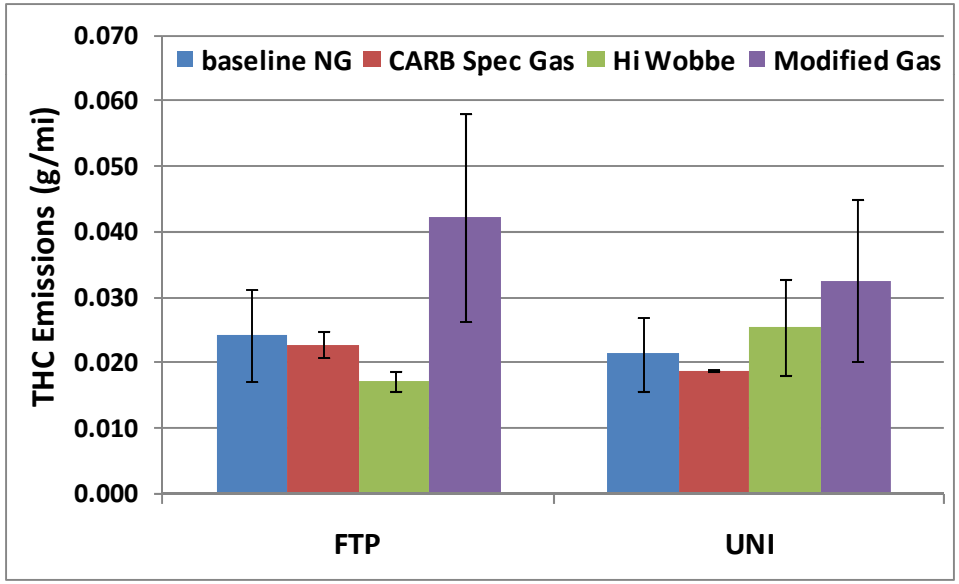


- Unified Cycle

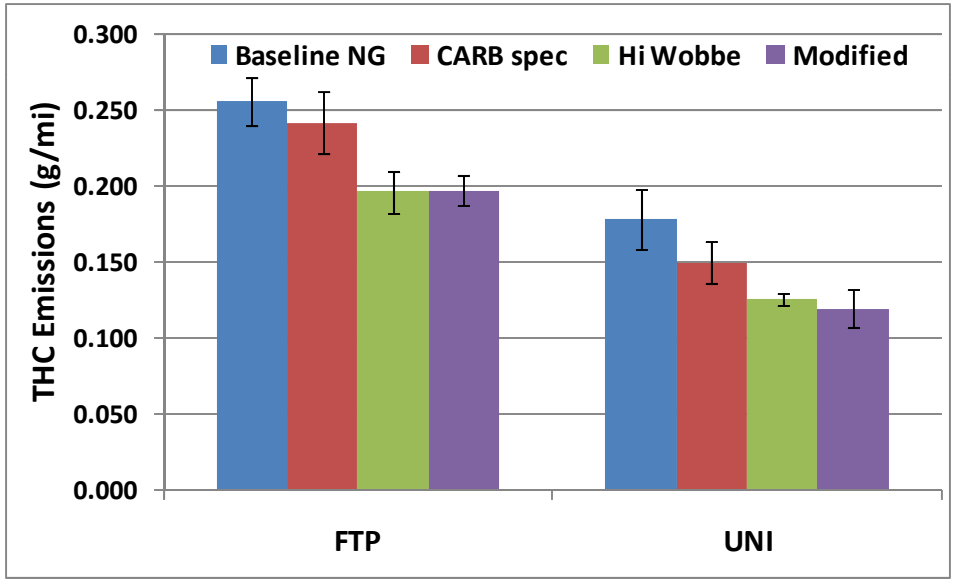


Light-Duty NGV Tests - THC Results

- THC showed opposite trends for vehicles.
- Sharp increases in THC emissions with the use of Modified Gas for Honda Civic over all operating conditions.
- For the Crown Victoria, the baseline gas had the highest THC emissions.



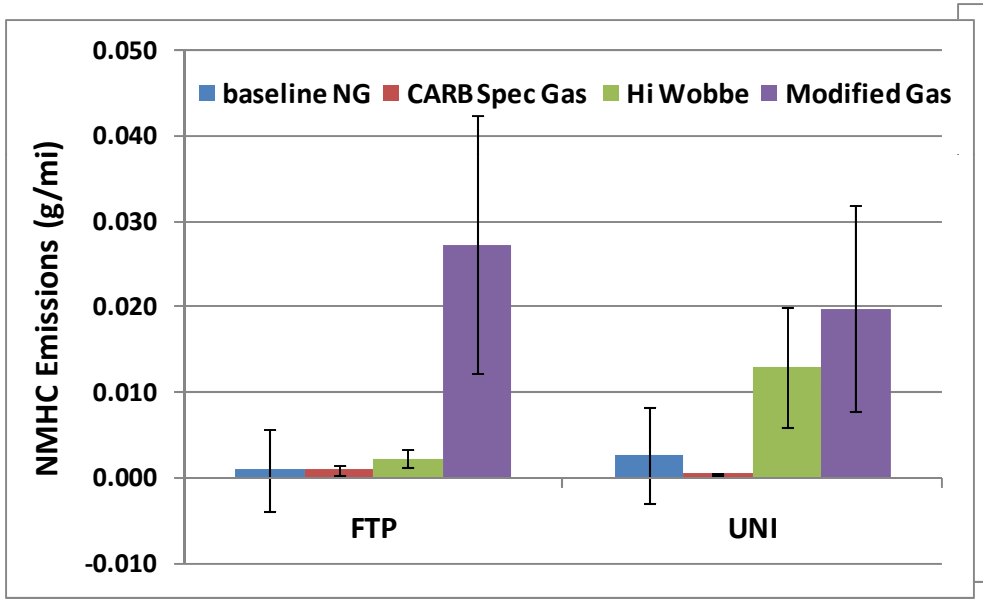
Honda Civic THC Results



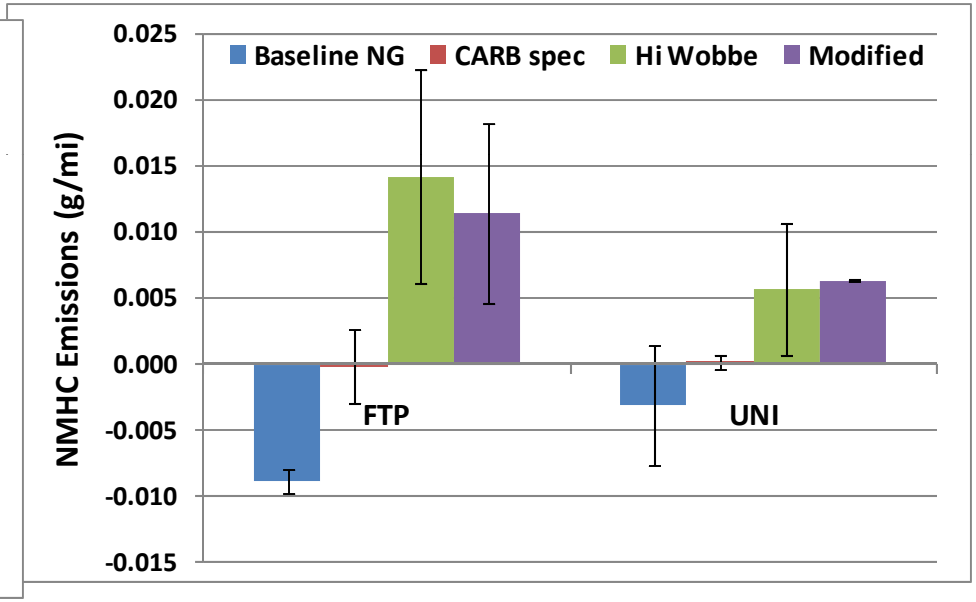
Ford Crown Victoria THC Results

Light-Duty NGV Tests - NMHC Results

- NMHC was only measureable for the modified and high wobbe
  - Especially during the cold start
- NMHC for CARB spec gas also measurable during cold start



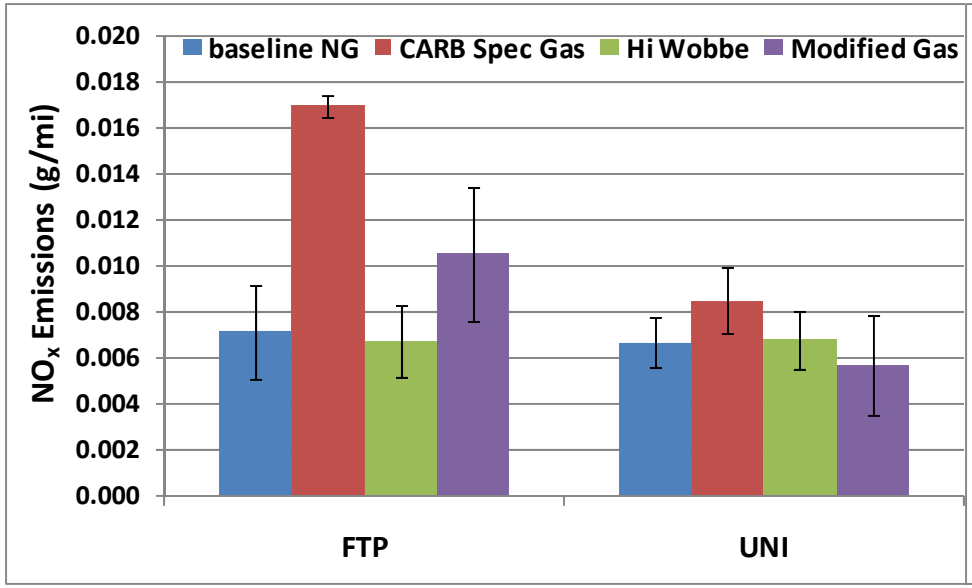
Honda Civic NMHC Results



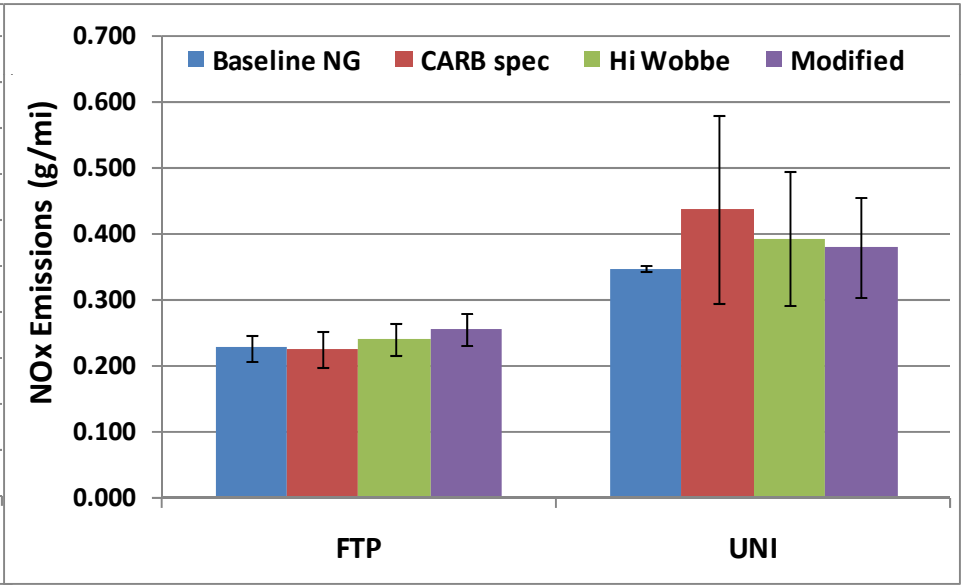
Ford Crown Victoria NMHC Results

Light-Duty NGV Tests - NO_x Results

- NO_x emissions did not show consistent trends over all cycles/vehicle/fuels
- For the Honda, NO_x emissions were higher for the CARB spec. gas.
- For the Crown Victoria, no statistically significant NO_x emissions impacts except under cold start.



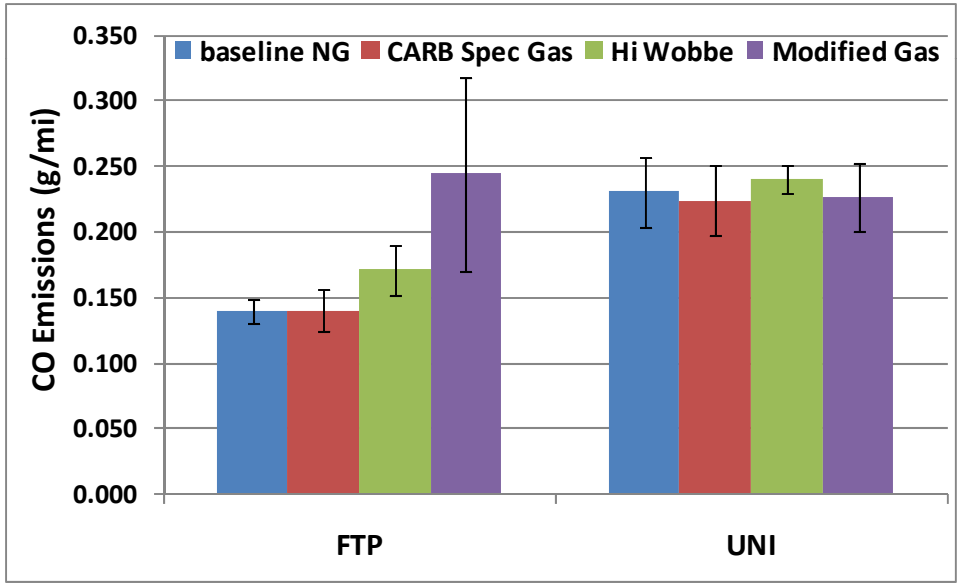
Honda Civic NO_x Results



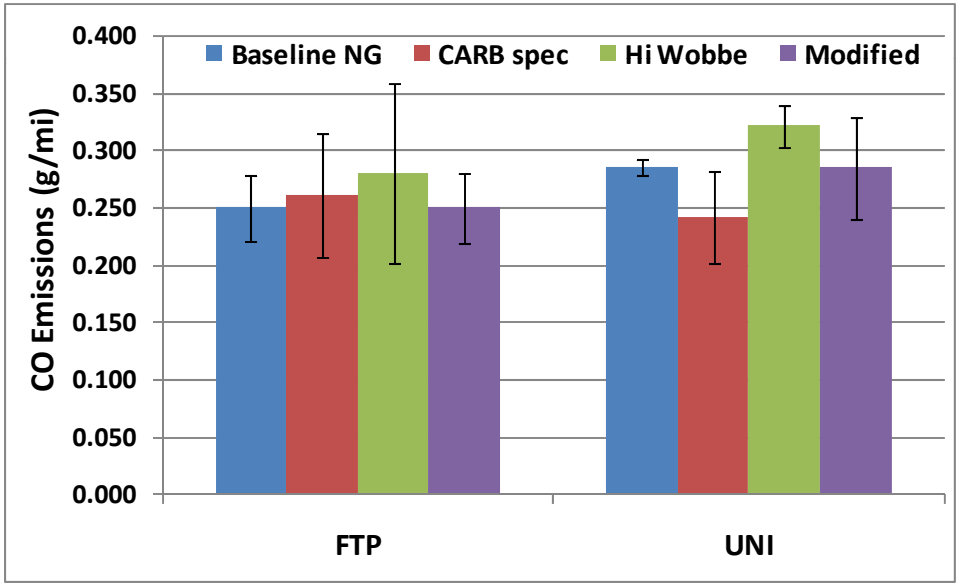
Ford Crown Victoria NO_x Results

Light-Duty NGV Tests - CO Results

- CO Emissions did not show significant trends in most cases.
- For Honda, CO emissions higher for modified Hi wobbe gas over FTP
- For Crown Vic, CO emissions were lower for CARB spec fuel and higher for the Hi Wobbe fuel over the Unified.
- Also some impacts during the cold start.



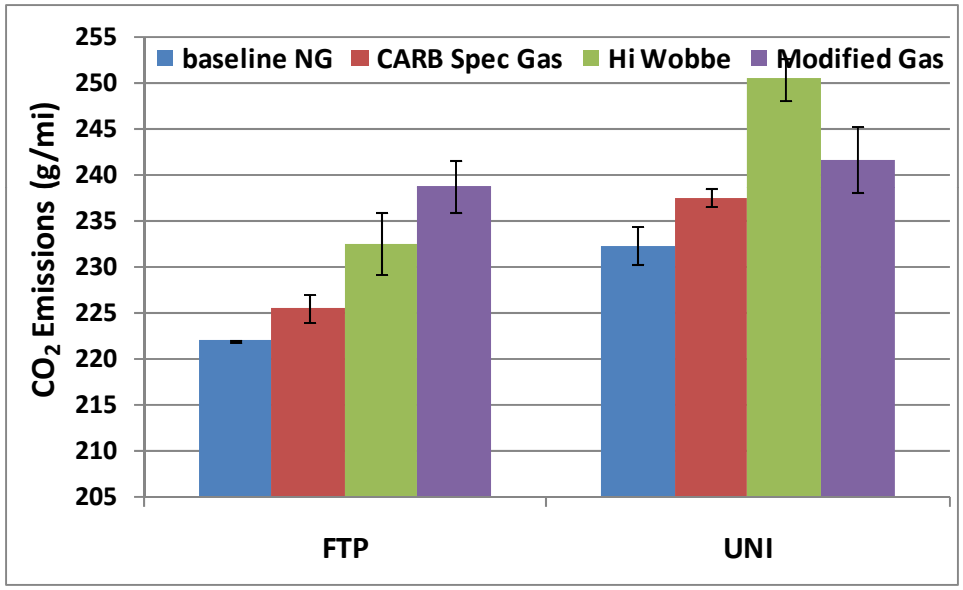
Honda Civic CO Results



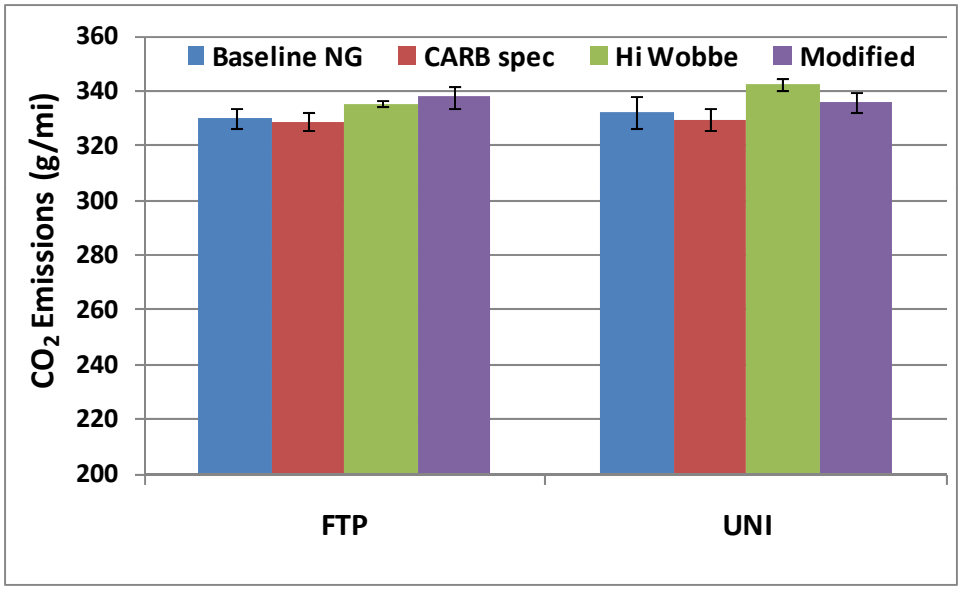
Ford Crown Victoria CO Results

Light-Duty NGV Tests – CO_2 Results

- CO_2 emissions were generally higher for the Hi wobbe and Modified blends.
- CO_2 emissions higher for CARB spec fuel during cold start for Honda.



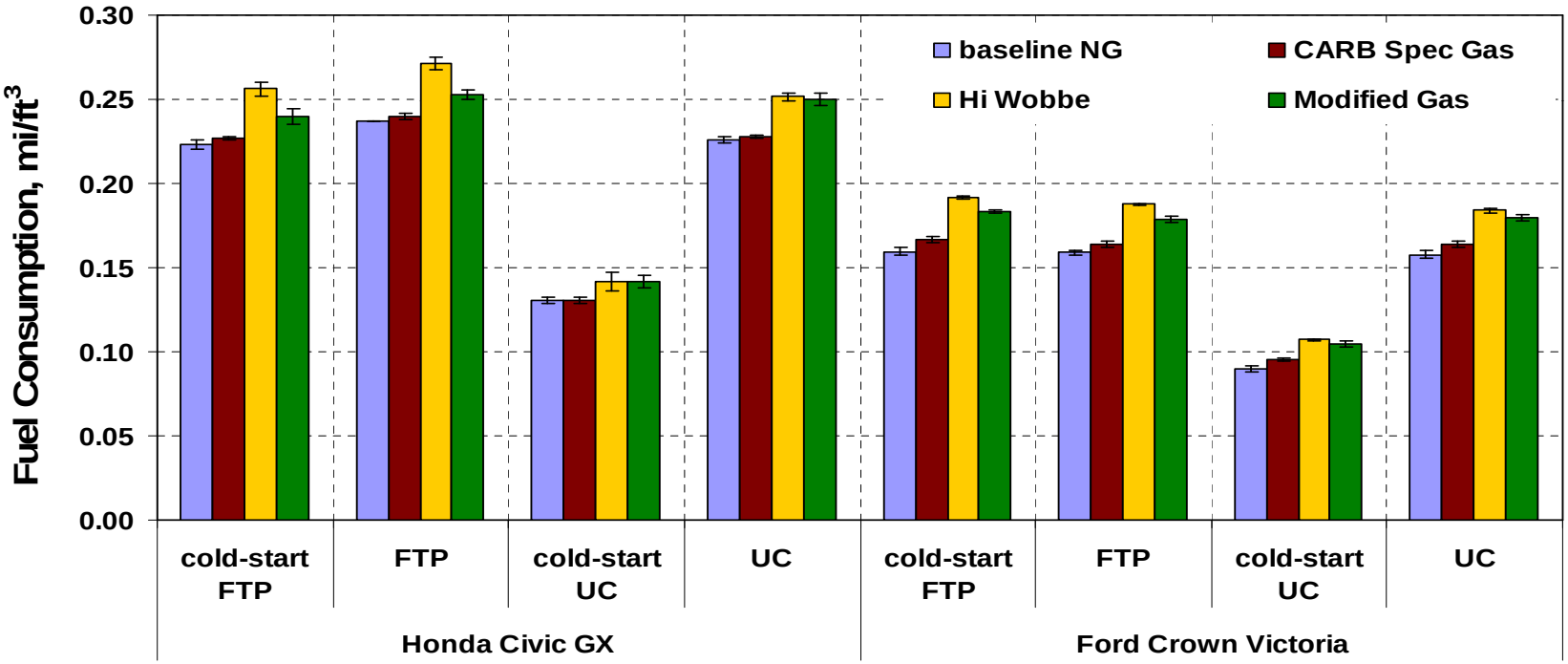
Honda Civic CO_2 Results



Ford Crown Victoria CO_2 Results

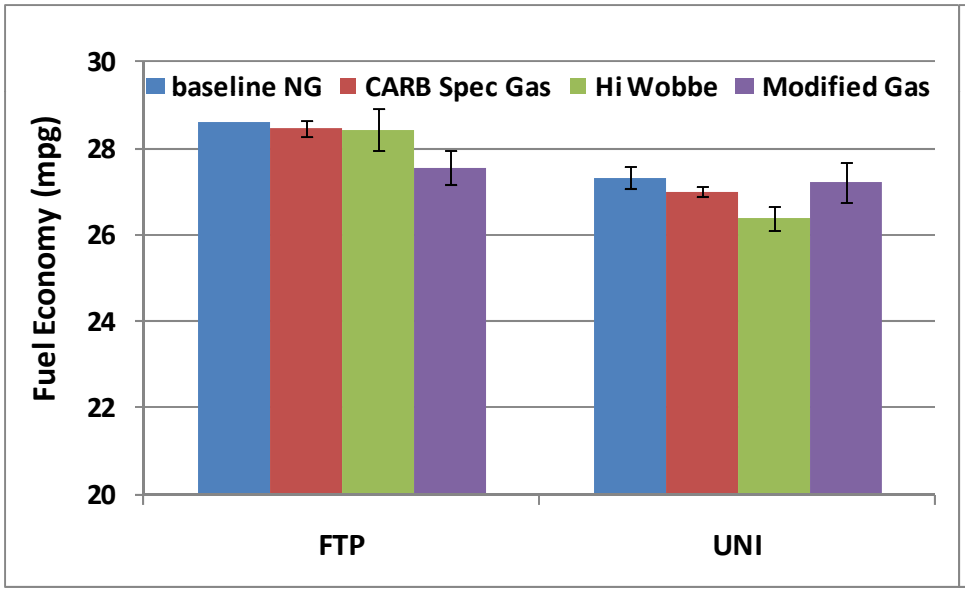
Light-Duty NGV Tests – Fuel Economy Results

- On a volumetric basis, the higher energy fuels (Hi Wobbe and Modified) showed the highest fuel economy.
- CARB spec fuel also had better fuel economy for many vehicle/cycle combinations.

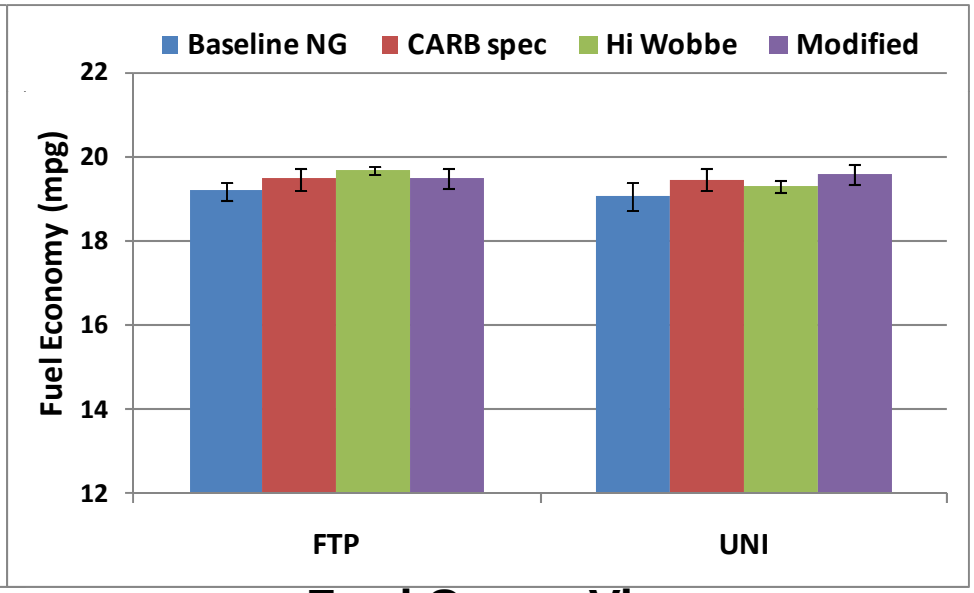


Light-Duty NGV Tests – Fuel Economy Results

- For Honda, some of the blends show lower “energy equivalent” fuel economy depending on the cycle.
- For Crown Vic, perhaps slightly higher “energy equivalent” fuel economy for some blends.



Honda Civic Fuel Economy Results



Ford Crown Vic Fuel Economy Results

Heavy-Duty Chassis Dynamometer Testing

- Testing to be conducted at CE-CERT's Heavy-Duty Chassis Dynamometer Test Facility
- Test Vehicles
  - Transit Bus with a 2009 Cummins ISL-G 8.9L - identified
  - Refuse Hauler with a Cummins 8.3L C-Gas Plus (use trans bus with same engine if vehicle can not be found)
  - Transit Bus with a 2003-2004 John Deere 8.1L 6081H engine - identified
- 6-7 fuel blends

Vehicle Selection

- John Deere engine 6081H bus
  - Older engine that comprises a substantial fraction of the school bus/transit bus population
- Cummins ISL-G bus
  - Newer engine that will be more representative of the future fleet
- Cummins C-Gas Plus Waste Hauler
  - Comprises high fraction of NGV waste hauler population
- A suggestion was made that the John Deere engine be replaced by a more modern Doosan or ESI engine
  - These new technologies composed too small a fraction of the fleet to impact the short term inventory
- Replacing the John Deere with C-Gas Plus transit bus also considered
  - It was decided to keep the wider range of engines

Gas blends for HD Chassis Dyno Testing

- Pipeline gas representative of Texas source (Baseline)
- Pipeline gas representative of Rocky Mountain source (Basline)
- Gas representative of Peruvian LNG
  - Highest heating value economical for Energia Costa Azul to process
- Gas representative of Middle Eastern blend LNG
  - High Wobbe number > 1400
  - Provides information on how emissions might change with more extreme compositional differences
- Two gases representative of gases located within the State with low methane numbers and varying HC composition
  - Will provide information on the effects of fuel composition on emissions in terms of varying HC percentages

Gas blends for HD Chassis Dyno Testing

Table 1. Test Fuel Specifications

Gas #	Description	methane	ethane	propane	I-butane	N2	MN	Wobbe #	HHV
1	Baseline, Texas Pipeline	96.08	1.78	0.37	0.16	1.62	100	1344	1020
2	Baseline, Rocky Mountain Pipeline	95.5	2.64	0.5	0.23	1.14	96	1360	1036
3	Peruvian LNG	88.3	10.5	0	0	1.2	84	1385	1083
4	Middle East LNG-Untreated	89.3	6.8	2.6	1.3	0	80	1428	1136
5	Associated High Ethane	83.65	10.75	2.7	0.2	2.7	75.3	1385	1115
6	Associated High Propane	87.2	4.5	4.4	1.2	2.7	75	1385	1116

- 7th gas will be LNG in the tank of the waste hauler at the time it is tested.
- The composition of this gas will be measured separately

HD Chassis Dyno Testing - continued

- Test cycles
  - Buses – Central Business District
  - Refuse Hauler – William H. Martin – refuse truck cycle
- Test Matrix

Table 2. Chassis Dynamometer Test Matrix For each Test Vehicle

Test Day	Morning Schedule (assumes 3 replicates)	Afternoon Schedule (assumes 3 replicates)
CBD or WHM Refuse Cycle		
Day 1	111	222
Day 2	222	333
Day 3	333	444
Day 4	444	555
Day 5	555	666
Day 6*	666	777
Day 7	777	111

1 = Gas #1, 2 = Gas #2, 3 = Gas #3, 4 = Gas #4, 5 = Gas #5

* Gas 777 will be used in the Waste Hauler

HD Chassis Dyno Testing - continued

- Measurements
  - Power map on each fuel – max power readings at 4-5 different speeds
  - THC, NMHC, CH_4, CO, NO_x, NO, NO_2, CO_2, and PM.
  - NH_3 sampling with a tunable diode laser
  - Carbonyls (including formaldehyde and acetaldehyde) via DNPH + HPLC
    - 3-4 tests per vehicle/fuel combination
  - PM number – 3022 CPC
  - real-time particle size – UCR's fast scan SMPS (secondary importance)
  - Possibility of additional analyses for PAHs being investigated

Central Business District Test Cycle

- 2 iterations of 560 second cycle with a warmup
- Average speed = 20.23 km/hr Driving distance = 3.22 km

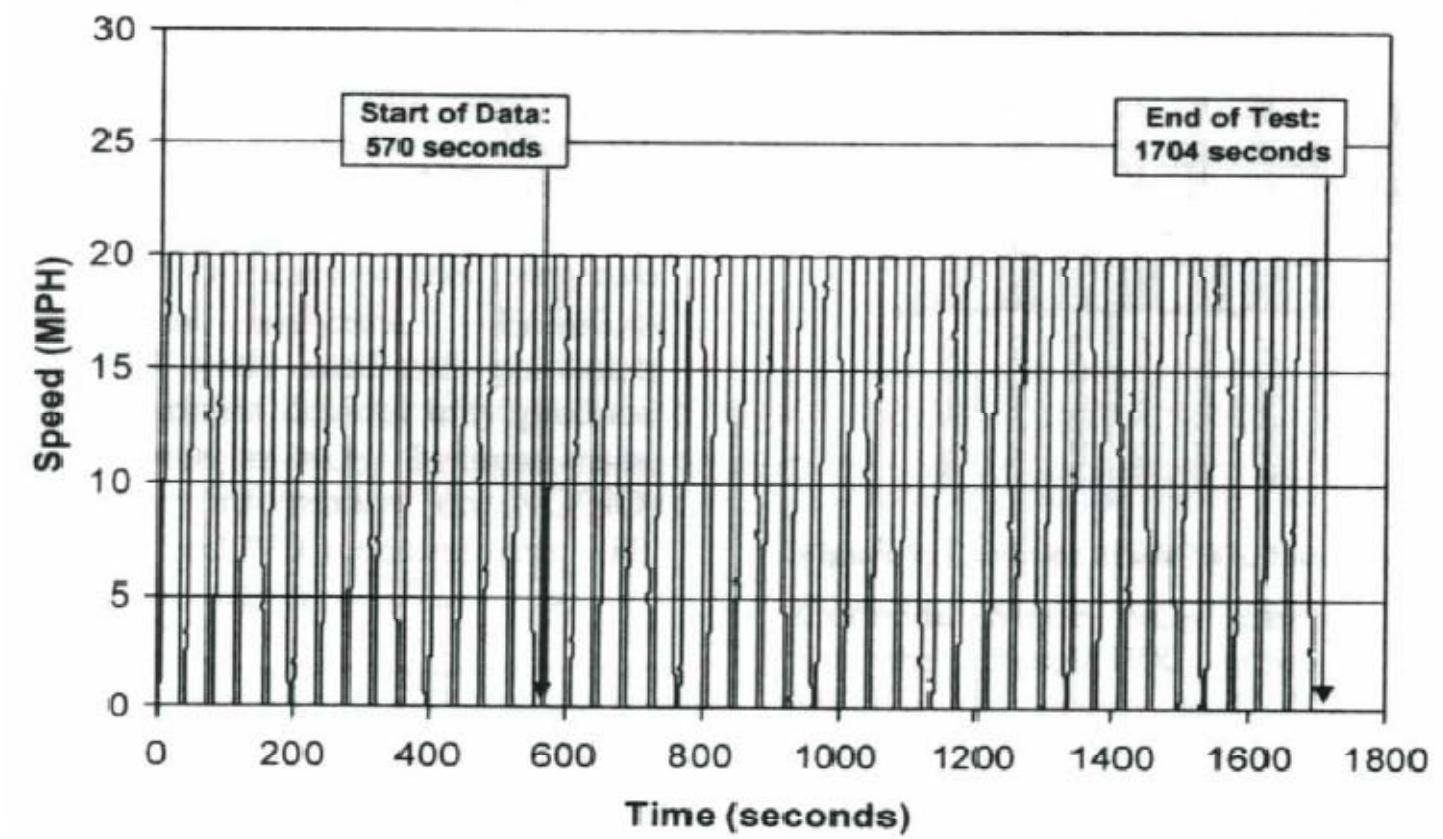


Figure 1. Double CBD Cycle with Warmup

Refuse Truck Test Cycle

- 3 sections: transport, curbside pickup, and compaction + warmup
- Compaction is final 155 seconds – use 30 mph + 80 hp load

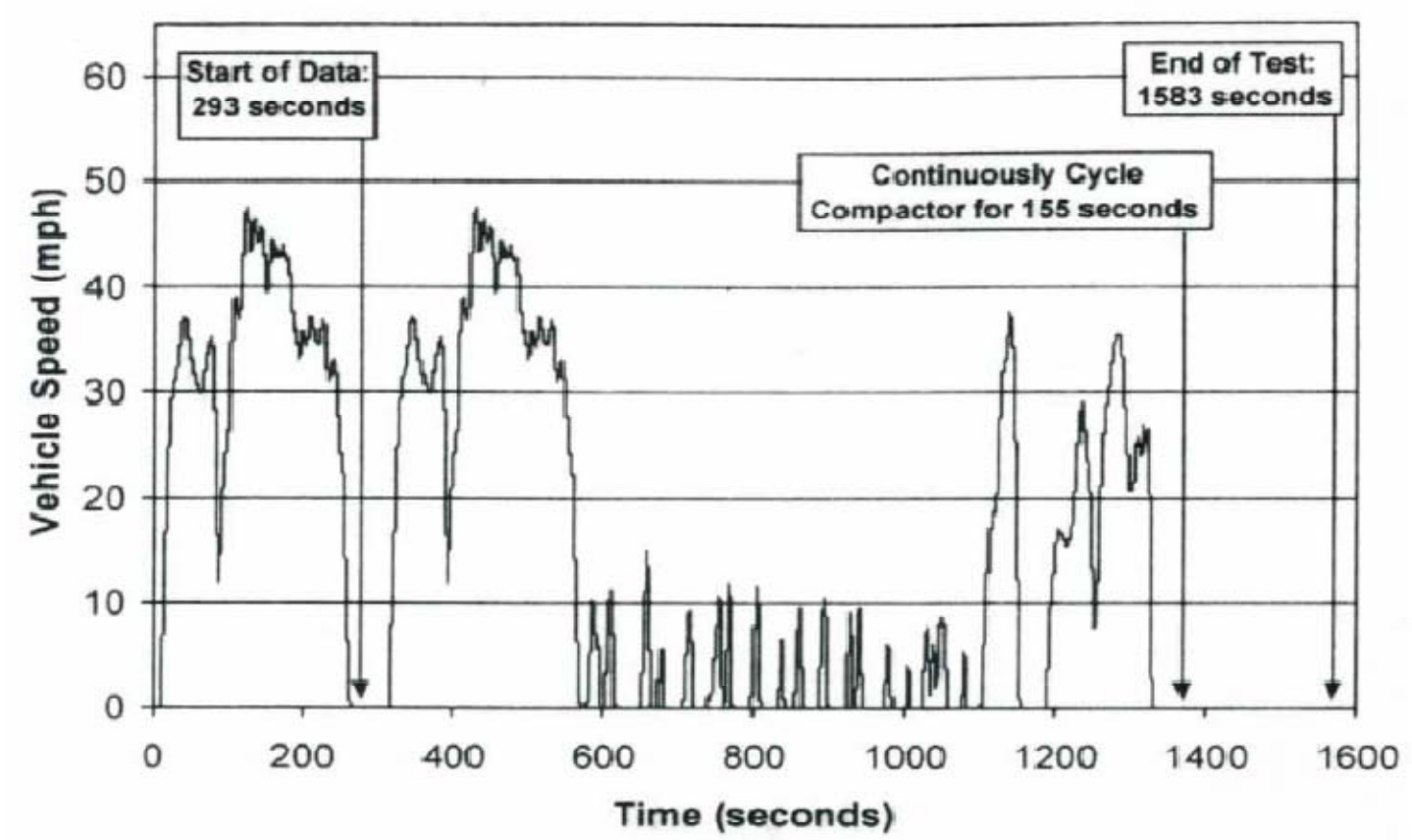


Figure 2. Refuse Truck Cycle

Program Schedule

- Light-duty Testing
  - Draft Memorandum and associated journal article on this testing completed and currently under review
- Heavy-duty Chassis Testing
  - Test gases should be ready for testing by late November/early December
  - Testing is planned for Dec. 2010 – Feb. 2011 (depending on availability of vehicles)
  - Draft Memorandum on this testing completed 3-4 months after completion of testing (including toxics and exotic species)